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## **Final Report for NASA Grant NAG5-1917**

### **Permanent GPS Geodetic Array in Southern California**

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## Summary

The southern California Permanent GPS Geodetic Array (PGGA) was established in the spring of 1990 to evaluate continuous Global Positioning System (GPS) measurements as a new tool for monitoring crustal deformation. Southern California is an ideal location because of the relatively high rate of tectonic deformation, the high probability of intense seismicity, the long history of conventional and space geodetic measurements, and the availability of a well developed infrastructure to support continuous operations. Within several months of the start of regular operations, the PGGA recorded far-field coseismic displacements induced by the June 28, 1992 ( $M_w=7.3$ ), Landers earthquake, the largest magnitude earthquake in California in the past 40 years and the first one to be recorded by a continuous GPS array. Only nineteen months later, on 17 January 1994, the PGGA recorded coseismic displacements for the strongest earthquake to strike the Los Angeles basin in two decades, the ( $M_w=6.7$ ) Northridge earthquake. At the time of the Landers earthquake, only seven continuous GPS sites were operating in southern California; by the beginning of 1994, three more sites had been added to the array. However, only a pair of sites were situated in the Los Angeles basin. The destruction caused by the Northridge earthquake spurred a fourfold increase in the number of continuous GPS sites in southern California within 2 years of this event. The PGGA is now the regional component of the Southern California Integrated GPS Network (SCIGN), a major ongoing densification of continuous GPS sites, with a concentration in the Los Angeles metropolitan region.

Continuous GPS provides temporally dense measurements of surface displacements induced by crustal deformation processes including interseismic, coseismic, postseismic, and aseismic deformation and the potential for detecting anomalous events such as preseismic deformation and interseismic strain variations. Although strain meters yield much higher short-term resolution to a period of about 1 year, a single continuous GPS site is significantly less expensive than a single strain meter and probably has better long-term stability beyond a 1-year period. Compared to less frequent field measurements, continuous GPS provides the means to better characterize the errors in GPS position measurements and thereby obtain more realistic estimates of derived parameters such as site velocities.

## Goals and Achievements of the Project

At the outset the stated goals of the PGGA project were:

“(1) To develop of methodologies for continuous millimeter-level crustal deformation monitoring with GPS. We need to understand and minimize the contributors to the GPS error spectrum over a broad range of temporal and spatial scales.

(2) To characterize the spectrum of strain in the space-time (or frequency-wavenumber) domain. At the moment we do not have a good knowledge of the spectrum of strain, except perhaps at Piñon Flats Observatory (run by SIO) and there only for a short baseline measurement. Therefore, we need to continuously observe over a wide spatial range from one kilometer (or less) to several hundred kilometers. Of course, we need to distinguish the strain spectrum "signal" from the GPS error spectrum "noise". We need to separate instrumental and software effects from unknown ground and monument effects.

(3) To improve procedures for efficient data collection, analysis, archiving and distribution. We are dealing with large amounts of data that must be analyzed quickly (within hours or less) and optimally, distributed broadly, and archived for more refined analysis.

(4) To detect temporal variations of strain. We will occupy sites of geophysical and geological interest within local networks that are actively being monitored with other geodetic and geophysical instruments and whose deformation rates are well constrained to provide some notion of "ground truth". We want to observe in areas that may exhibit temporal variations in strain and where earthquakes are likely to occur.”

All of these goals have been met and exceeded as evidenced by the SCIGN project. The PGGGA was fortunate to have collected data for 2 earthquakes as indicated in the summary. The measurements of postseismic deformation induced by the Landers earthquake are an extremely valuable geophysical data set.

Other noteworthy outcomes of this project not described in the numerous publications listed below.

- (1) An open and free data policy that has become a standard for continuous GPS arrays.

- (2) The use of the PGGA as a primary source of geodetic control in southern California for surveying and engineering applications, and to the development of the California Spatial Reference Center.

## **Publications**

The primary and definitive references for the PGGA project are two papers published in 1993 in *Nature* (Bock et al., Blewitt et al.), a trilogy of papers published in *Journal of Geophysical Research* in 1997 (Bock et al., Zhang et al., Wdowinski et al.), and a Ph.D. thesis by J. Zhang, in addition to another 17 journal articles and book chapters (all listed below) and numerous reports, abstracts, and proceedings (not listed).

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### **World Wide Web**

SOPAC: [lox.ucsd.edu](http://lox.ucsd.edu)

SCIGN: [www.scign.org](http://www.scign.org) (and related web pages)

**Acknowledgments.** The PGGA was established in 1990 by Scripps Institution of Oceanography and the Jet Propulsion Laboratory, with the participation of Massachusetts Institute of Technology, California Institute of Technology, University of California Los Angeles, U.S. Geological Survey (Pasadena), Riverside Flood Control and Water Conservation District, and Riverside County Transportation Division. We appreciate the support of our colleagues including Shelley Marquez, Myra Medina, Rosa Felice, Rosemary Leigh, Veronica Dubrovskaya, Paul Tregoning, Paul Henkart, Seiichi Shimada, Peter Worcester, Kevin Hardy, Steve Bralla, and Harold Bolton at Scripps Institution of Oceanography; John Scheid, Ulf Lindqwister, Mike Watkins, Bill

Melbourne, Larry Young, Tim Dixon, Geoff Blewitt, Tom Yunck, Ruth Neilan, Tom Meehan, and the Deep Space Network group at JPL; Brad Hager and Simon McClusky at MIT; Gerald Doyle and Mark Madeiros at Riverside Flood Control and Water Conservation District; Gerald Stayner and Brian Hess at the Riverside Transportation Division; Don Hunter, John Fundus, and Larry Fenske at Caltrans; Steve Salyards and Zheng-kang Shen at UCLA; Hiroo Kanamori, Egill Hauksson, and Kerry Sieh at Caltech; Jonathan Ladd, Tom Hunter, Sergei Gourevitch, and James Stowell at Ashtech, Inc.; Ken Moymann at Trimble Navigation; and Boudewijn Ambrosius at Delft University of Technology. We thank John Orcutt, Bernard Minster, Edward Frieman, and Tom Collins at Scripps for their encouragement and support of this work since its inception, and Kei Aki, Tom Henyey, and John McRaney at SCEC/USC. Our many colleagues at the International GPS Service for Geodynamics and the International Earth Rotation Service have graciously made the global tracking and reference frame data available. This work was supported by NASA (NAGW-2641, **NAG-5-1917**, NASW 3007, NAG5-3550), USGS (14-08-0001-G1673, 1434-92-G2196, 1434-95-G2629), NSF (EAR 92 08447, EAR 94 16338), SCEC (PO 569930, Cooperative Agreement EAR-8920136, USGS Cooperative Agreement 14-08-001-A0899), Riverside County Flood and Water Conservation District, Riverside County Transportation Division, and California Department of Transportation, and Ida and Cecil Green Fellowship.